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Phosphorous and Potassium Uptake by Rye Seedlings and Ion Exchange Papers As Influenced by Soil Density and Aeration

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EXPERIMENTAL MATERIALS AND METHODS

Bulk soil samples of Wharton clay loam and Monongahela sandy clay loam soils used in the studies were collected from the 1- to 6-inch depths, moist sieved through a 1/4-inch screen, air dried, and stored in plastic bags. Some chemical and physical characteristics of the soils are shown in Table 1. Organic matter was determined by the modified Walkley-Black method (25), pH by the glass electrode and a 1:1 soil: water suspension, available phosphorus and potassium by the West Virginia University soil testing laboratory, and particle size distribution by the Bouyoucos method (2).

Amberlite ion exchange papers[1] are specialty filter papers prepared from alpha-cellulose pulp and finely ground ion exchange resins. Table 2 gives some characteristics of the ion exchange papers used. Preliminary tests were conducted with the papers to determine their adsorption of phosphorus or potassium ions from solutions of known concentration and how to extract the adsorbed ions. It was determined that nearly all the phosphorus adsorbed by the WB2 form could be removed by four successive extractions with a .01 N NH_4F-HCl mixture. Four successive extractions with .01 N HCl removed nearly all the potassium from the WA2 form.

Bulk samples of the air-dried soils were weighed to give bulk densities of 1.3 and 1.5 g/cc when compacted in 3 by 3-inch brass cylinders consisting of two 1 1/2 by 3-inch diameter cylinders taped together. Each soil sample was spread on a sheet of paper, moistened uniformly with a fine spray of KH_2PO_4 solution containing 9 g/l, thoroughly mixed and compacted in the cylinder with a Carver hydraulic press. The volume of solution used to moisten the soil was calculated to provide 120 or 240 pounds per acre equivalent of phosphorus and 140 or 280 pounds per acre equivalent of potassium. Only the data on uptake by rye seedlings and ion exchange papers for the high rates of phosphorus and potassium are presented because there was no appreciable difference between the high and low rates of application. Each cylinder of compacted soil was slowly wetted to saturation by capillarity in a large tank. Aeration porosities of approximately 5, 10, and 15 per cent were established within each bulk density by removing water from the saturated soils by vacuum.

Phosphorus and Potassium Uptake by Ion Exchange Paper

The two halves of each cylinder were separated and a 3-inch diameter circle of the appropriate Amberlite ion exchange paper placed between the two halves. The halves were retaped together and placed in

[1] The ion exchance papers were secured from H. Reeve Angel and Co. Inc., 9 Bridewell Place, Clifton, New Jersey.

TABLE 1
Chemical and Physical Characteristics of the Soils

Soil	Organic Matter	pH	Available P	Available K	Particle Size Distribution: Sand 2-0.02mm	Silt 0.02-0.002mm	Clay 0.002mm
	%					%	
Monongahela	1.03	6.1	Medium	Low	63.2	12.5	24.3
Wharton	2.37	6.5	Medium	Low	25.1	40.3	34.6

a constant humidity chamber. The paper remained in contact with the soil for periods up to 7 days. At 2, 4, 5, 6 and 7 days the papers were removed, rinsed with distilled water, and phosphorus and potassium extracted from the papers with the proper solution. Potassium was determined directly on an aliquot with a Beckman DU model 2400 flame spectrophotometer. Phosphate was determined by the molybdate-blue method (3).

Phosphorus and Potassium Uptake by Rye Seedlings

Root mats of rye seedlings were produced to measure short-term phosphorus and potassium uptake. Sand passing a 10-mesh but retained on a 20-mesh screen was chemically treated with 1 N HCl and 10 per cent H_2O_2 to remove any nutrient ions or organic matter, washed with de-ionized water, and dried. Thirty viable rye seeds were placed on the sand held in a 1 1/2 by 3-inch diameter brass cylinder, covered with an additional 30 grams of sand and watered with a nutrient solution minus phosphorus and potassium. The seeds were germinated in a constant temperature laboratory and grown until signs of phosphorus or potassium deficiencies appeared, usually about 8 days. Watering during growth was done daily with the appropriate nutrient solution. Eight days after planting roots had completely penetrated the bottom of the sand. Rather uniform root mats were obtained by careful control of the laboratory temperature and watering procedure. The 1 1/2 by 3-inch diameter cylinders containing the rye plants were placed in direct contact with the 1 1/2 by 3-inch diameter cylinders containing soil prepared in the same manner as for the ion exchange paper study. After growth periods of 2, 4, 5, 6, and 7 days the cylinders containing the rye plants were placed on a nest of screens (10 and 20 mesh) and the sand and soil gently washed from the plants. The plant material retained on the two screens was then rinsed, dried, ashed, and analyzed for phosphorus or potassium.

RESULTS

The uptake of potassium by the ion exchange papers and rye seedlings is shown in Figures 1-4. Potassium uptake generally increased in both

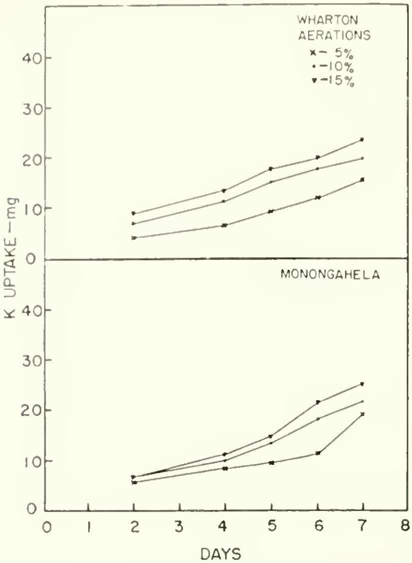

FIGURE 1. Potassium uptake by Amberlite ion exchange paper from Wharton and Monongahela soils with a bulk density of 1.3 g/cc as affected by aeration and time.

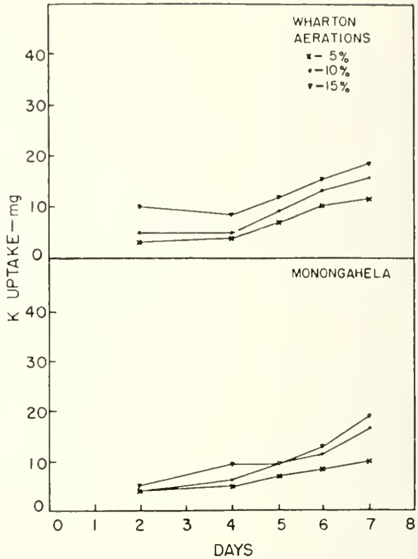

FIGURE 2. Potassium uptake by Amberlite ion exchange paper from Wharton and Monongahela soils with a bulk density of 1.5 g/cc as affected by aeration and time.

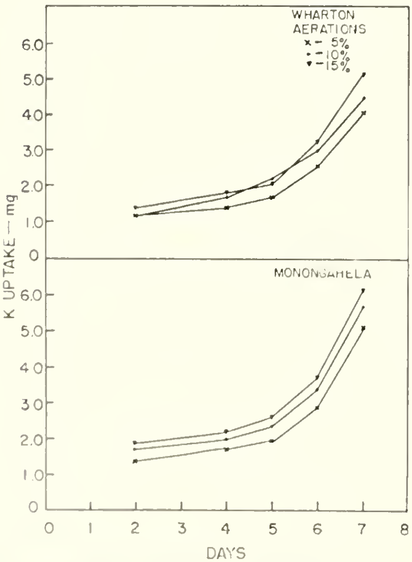

FIGURE 3. Potassium uptake by rye seedlings from Wharton and Monongahela soils with a bulk density of 1.3 g/cc as affected by aeration and time.

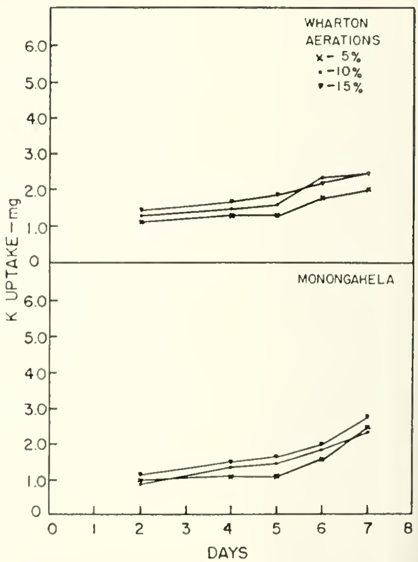

FIGURE 4. Potassium uptake by rye seedlings from Wharton and Monongahela soils with a bulk density of 1.5 g/cc as affected by aeration and time.

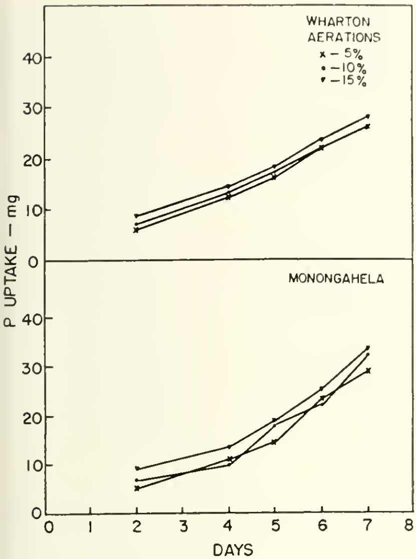

FIGURE 5. Phosphorus uptake by Amberlite ion exchange paper from Wharton and Monongahela soils with a bulk density of 1.3 g/cc as affected by aeration and time.

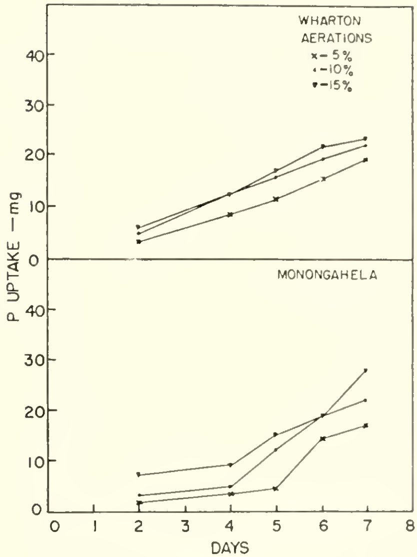

FIGURE 6. Phosphorus uptake by Amberlite ion exchange paper from Wharton and Monongahela soils with a bulk density of 1.5 g/cc as affected by aeration and time.

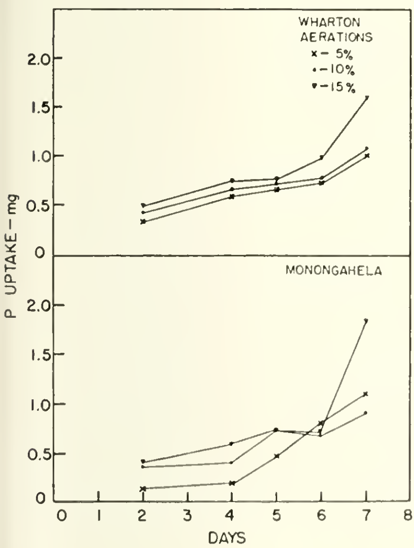

FIGURE 7. Phosphorus uptake by rye seedlings from Wharton and Monongahela soils with a bulk density of 1.3 g/cc as affected by aeration and time.

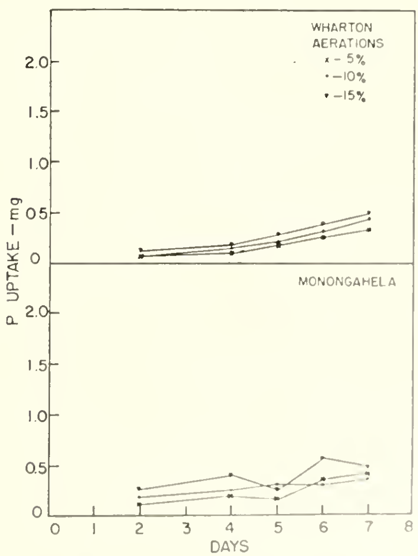

FIGURE 8. Phosphorus uptake by rye seedlings from Wharton and Monongahela soils with a bulk density of 1.5 g/cc as affected by aeration and time.

the Monongahela and Wharton soils with time and per cent aeration but decreased with an increase in bulk density from 1.3 to 1.5 g/cc. The decreased uptake with increased bulk density is more pronounced with the rye seedlings than with the ion exchange paper.

The uptake of phosphorus by the ion exchange paper and rye seedlings is shown in Figures 5-8. As occurred with potassium uptake, phosphorus uptake for both soils increased with time and per cent aeration but decreased with increased bulk density. Phosphorus uptake with time by the ion exchange paper is nearly a linear relationship for the Wharton but not the Monongahela soil. More phosphorus than potassium was taken up by the ion exchange paper for both soils and both bulk densities. However, with the rye seedlings the reverse occurred. Little phosphorus was taken up by the rye seedlings from either soil at a bulk density of 1.5 g/cc.

As time of treatment progressed, especially with the Monongahela soil, greater spread of phosphorus and potassium uptake occurred with the rye seedlings when comparing the low to the high bulk density (compare Figure 7 with 8 and 3 with 4).

DISCUSSION

The adverse effects of high soil density on plant growth are restricted root proliferation, low soil aeration, reduced infiltration of water, and slower movement of gravitational and film water in the soil. Consequently root systems in dense soils absorb less nutrients because they are smaller, more stunted, may receive insufficient oxygen, and because ions diffuse more slowly to root surfaces.

It is extremely difficult to separate the effects of aeration on plant growth from those of mechanical impedance and/or slower diffusion of ions to root surfaces because they are so interrelated. This study by using a nonbiological adsorber of ions (exchange paper) in addition to a biological absorber (roots) gives some evidence that soil density has an effect on nutrient absorption independent of aeration or mechanical impedance. There was no visible evidence of mechanical impedance in either soil at a bulk density of 1.3 g/cc. Further it was not expected that aeration would be important in adsorption by the ion exchange paper. The fact that aeration porosity within bulk densities did affect the adsorption of phorphorus and potassium by the exchange paper appears to indicate that diffusion of ions to the papers was affected. This may have been due to the manner in which aeration was adjusted within bulk density levels, viz by addition or removal of water. Increasing aeration by removing water from the larger soil pores would increase the ionic concentration in the soil solu-

tion and increase the rate of diffusion to the ion exchange paper (sink). The increase in the number of smaller pores in both soils as a result of increasing the bulk density from 1.3 to 1.5 g/cc at each of the aeration levels decreased the adsorption of phosphorus and potassium. This appears to indicate that the increased bulk density largely influenced the diffusion of the ions; possibly through tighter water retention by soil particles in the smaller pores and changes in the size and continuity of diffusion channels. It is possible that if bulk densities less than 1.3 g/cc had been used, results similar to those of Flocker *et al.* (7) would have been obtained; that is, that there is less nutrient uptake at both low and high bulk densities. Maximum diffusion of phosphorus and potassium occurred at bulk density less than 1.5 g/cc in both soils. It was expected that it might occur at or above 1.5 g/cc for the sandy Monongahela soil. Philips and Brown (19) found that maximum diffusion of Sr^{89} occurred at different bulk densities in two soils. In a Sharkey clay it occurred at a bulk density of 1.31 g/cc, while in a Dundee silt loam it occurred at 1.58 g/cc.

With rye seedlings and a bulk density of 1.3 g/cc phosphorus and potassium uptake was probably reduced by lower aeration (at the 10 and 5 per cent level) and by slower diffusion of ions to the roots. The roots did not penetrate the soil as well at the 5 and 10 per cent aeration levels as at the 15 per cent level. At a bulk density of 1.5 g/cc there was visible evidence of mechanical impedance to the roots even at the 15 per cent aeration level. It is doubtful that aeration, *per se*, had much effect on phosphorus and potassium uptake with the Monongahela soil, especially at the 15 per cent aeration level. In a previous study (26) with this soil, the aeration porosity after compaction to a bulk density of 1.7 g/cc was still 18.1 per cent. It was not possible to get reducing conditions in this soil as measured by nitrogen transformations at this bulk density.

The much greater uptake of phosphorus and potassium by the exchange paper is largely due to there being no environmental effects on uptake by the exchange paper and to much greater contact with the soil surface. The exchange papers were in contact on both sides with treated soil. The lack of linear relationship between the uptake of phosphorus and potassium by the exchange papers and time may partially be due to some time being required to obtain good contact between the soils and exchange paper. Non-linearity is greatest for the sandier Monongahela soil. The reasons for greater uptake of phosphorus than potassium by the exchange papers are not known. The exchange paper used for adsorption of potassium has a greater exchange capacity than that used for phosphorus (Table 2).

The greater spread of phosphorus and potassium uptake, especially for the Monongahela soil, with time when comparing the low to the high bulk density indicates the rye roots after 4 days were rapidly permeating the soil at bulk density 1.3 g/cc but not at 1.5 g/cc.

TABLE 2

Characteristics of the Amberlite Ion Exchange Papers

Amberlite Designation	WA2	WB2
Ionic Form	H	OH
Ion Adsorbed	K	P
Approximate Exchange Capacity me./cm^2	0.056	0.044

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